

AN OVERVIEW OF THE SPACE ENVIRONMENTS AND SPACECRAFT EFFECTS ORGANIZATION CONCEPT

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ABSTRACT

The National Aeronautics and Space Administration (NASA) is embarking on a course to expand human presence beyond Low Earth Orbit (LEO) while also expanding its mission to explore our Earth, and the solar system. Destinations such as Near Earth Asteroids (NEA), Mars and its moons, and the outer planets are but a few of the mission targets. Each new destination presents an opportunity to increase our knowledge on the solar system and the unique environments for each mission target. NASA has multiple technical and science discipline areas specializing in specific space environments fields that will serve to enable these missions. To complement these existing discipline areas, a concept is presented focusing on the development of a space environment and spacecraft effects (SESE) organization. This SESE organization includes disciplines such as space climate, space weather, natural and induced space environments, effects on spacecraft materials and systems, and the transition of research information into application. This space environment and spacecraft effects organization will be composed of Technical Working Groups (TWG). These technical working groups will survey customers and users, generate products, and provide knowledge supporting four functional areas: design environments, engineering effects, operational support, and programmatic support. The four functional areas align with phases in the program mission lifecycle and are briefly described below. Design environments are used primarily in the mission concept and design phases of a program. Environment effects focuses on the material, component, sub-system, and system-level response to the space environment and include the selection and testing to verify design and operational performance. Operational support provides products based on real time or near real time space weather to mission operators to aid in real time and near-term decision-making. The programmatic support function maintains an interface with the numerous programs within NASA, other federal government agencies, and the commercial sector to ensure that communications are

well established and the needs of the programs are being met. The programmatic support function also includes working in coordination with the program in anomaly resolution and generation of lessons learned documentation. The goal of this space environment and spacecraft effects organization is to develop decision-making tools and engineering products to support all mission phases from mission concept through operations by focusing on transitioning research to application. Products generated by this space environments and effects application are suitable for use in anomaly investigations. This paper will describe the scope and purpose of the space environments and spacecraft effects organization and describe the TWG's and their relationship to the functional areas.

1. INTRODUCTION

NASA has identified six strategic goals for 2011¹. These goals are the top level challenges for the Agency and drive Agency decisions for the future. The exploration of space beyond Low Earth Orbit (LEO) is identified in many of the strategic goals for 2011. Specifically, these goals are: 1) 'extend and sustain human activities across the solar system'; 2) 'expand scientific understanding of the Earth and the universe in which we live'; 3) create the innovative new space technologies for our exploration, science, and economic future'; 4) 'advance aeronautics research for societal benefit'; 5) 'enable program and institutional capabilities to conduct NASA's aeronautics and space activities'; 6) 'share NASA with the public, educators, and students to provide opportunities to participate in our mission, foster innovation and contribute to a strong National economy.' These goals describe an achievable and technically challenging objective. Integrated within these goals are robotic precursor missions to destinations such as Near Earth Objects (NEO), the lunar surface, solar system planets, and the Lagrange points.

Additional facets of these goals include commercial crew and cargo to transport humans to the International Space Station (ISS), the development of Earth and climate observatories, and expanded planetary, astrophysics, and heliophysics science missions. These initiatives and missions will be executed within multiple Directorates and require the expansion of existing Programs and establishment of new Programs. An Agency-level Space Environments and Spacecraft Effects (SENSE) organization would provide a cost-effective means to increase the National collective knowledge and provide a peer-reviewed suite of tools for engineers and designers to use in support of exploration Programs. The SENSE organization would develop and maintain a National capability providing coordination amongst existing space environments related entities, develop products to support design, development, and operation of spacecraft systems that will accommodate or mitigate effects due to the presence of the space environment. SENSE would disseminate that information for Agency, inter governmental, industry, academia, and international use while providing a cost-effective means to increase our collective knowledge and provide a peer-reviewed suite of tools for scientists, engineers, and designers to use.

A goal of the space environments and spacecraft effects organization is to transition research to applications enabling the collection, development and dissemination of space environment knowledge required to perform mission concepts studies, design, manufacture, and operate reliable, cost-effective spacecraft for the government and commercial sectors. SENSE would manage the development of products that enable spacecraft programs to accommodate or mitigate the effects of the space environment while ensuring continuity of SENSE knowledge. This space environments and spacecraft effects organization will strive to ensure synergy by working in coordination with existing space environment, space weather, and spacecraft effects entities. The term 'coordination' in this context is defined as two or more organizations working together in a way that enhances their capabilities through multiplication of efforts, and does not render either organization dependent on the other.

2. ORGANIZATION FUNCTION, STRUCTURE AND RESPONSIBILITIES

The space environments and spacecraft effects (SENSE) organization consists of a management office whose responsibilities include performing knowledge gap analysis in the National space environments and spacecraft effects community, competitively funding the development of products to close the knowledge gap, management of the contractual agreements, dissemination of products, communicating with Programs, Agency leadership, and the technical community. The SENSE management office consists of a chief, a deputy, subject matter experts, administrative and support personnel. International partnerships will be coordinated by the SENSE management office.

The Space Environments and Spacecraft Effects organization will communicate with the existing space environments related entities and facilitate coordination across the space

environments disciplines. The SENSE organization will develop products and provide technical knowledge in four functional areas that align with mission life cycle phases, as shown in figure 1. These functional areas are not staffed organizations; rather they serve as an indicator to the nature and usage of the product being generated. The functional areas are; Design Environments, Environment Effects, Operational Support, and Programmatic Support. Design environments are used primarily in the mission concept and design phases of a program. Environment effects focuses on the material, component, sub-system and system-level selection and the testing to verify design and operational performance. Operational support provides products based on real time or near real time space weather to mission operators to aid in real time and near-term decision-making. The programmatic support function maintains an interface with the numerous programs within NASA and the federal government to ensure that communications are well established and the needs of the programs are being met. The programmatic support function also includes working in coordination with the program in anomaly resolution and generation of lessons learned documentation.

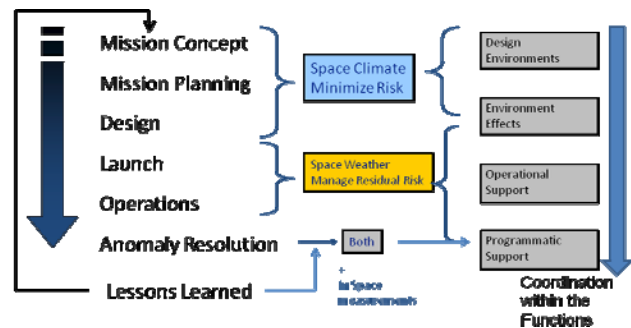


Fig. 1. Space Environment Model Use in the Mission Life Cycle

An example of a space environments and spacecraft effects organizational structure is shown in figure 2. The SENSE has a management office to oversee the operations of the organization. The SENSE office is responsible for ensuring product development alignment with Agency goals and objectives, coordination amongst pre-existing space environment, space weather, space environmental effects entities to identify, reduce or eliminate unwanted redundancy in the development of space environment related products. The SENSE office is responsible to conduct workshops, meetings, surveys, and use available means to determine gaps in the discipline of space environments and spacecraft effects. Once gaps are identified then SENSE would coordinate with, if warranted, existing organizations to develop strategies, advocate for, or provide funding to develop knowledge and close identified gaps. The SENSE office is responsible for the appropriate dissemination of products.

The part of the organization that significantly influences the year to year direction and activities resides within the technical working groups (TWGs), which are in turn comprised of subject matter experts (SMEs) in their respective disciplines. These SME's are the scientists and engineers supporting

government and commercial spacecraft development flight programs, professors in academia, and experts residing in science and engineering organizations throughout the Nation. The SME's that constitute membership in the TWG's are also associated with professional societies, other national, and international, space environment organizations and thus are able to serve as a common interface that links the existing discipline specific entities to the SENSE and vice-versa. SENSE will host a workshop every year to assemble the TWG SME's in a structured forum. This forum will be used to gather information for gap assessments, and provide technical interchange within the SME's through technical presentation format. The yearly workshop, hosted by SENSE will also serve to 'stitch' together the various space environment-related organizations within NASA, other government agencies, the commercial sector, academia, and internationally.

Products developed by the TWG's will support all phases of the Program mission life cycle. For example, a Charged Particle (CP) TWG could develop a data set of design environments suitable for early mission concept studies and near-real time empirical models that provide spacecraft operational support. A Space Environmental Effects (SEE) TWG could provide systematic data of radiation effects on the latest materials used in spacecraft components. An Interplanetary and Extraterrestrial Environments (IEE) TWG could provide expected outgassing of near-earth asteroids. These conceptual TWGs are described in more detail in the next three sub-sections.

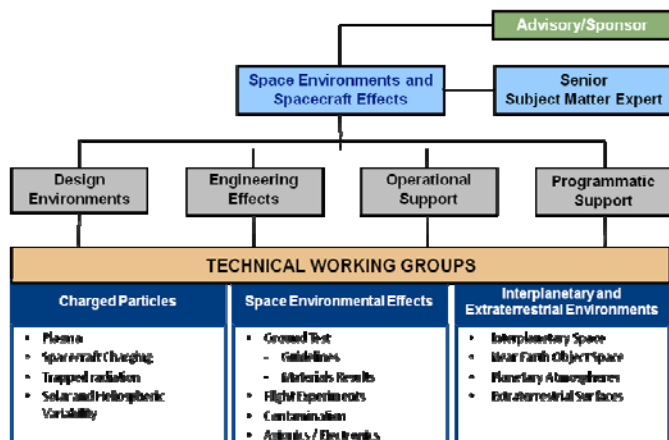


Fig 2. An example of an organizational structure concept for the space environments and spacecraft effects organization

2.1 Charged Particles (CP) TWG

The CP TWG will use co-chairs and working group members chosen based on their expertise in various aspects of the discipline area. The TWG will meet yearly to define products and their priorities based on needs of the various stakeholders in the spacecraft design and operations communities. There is considerable synergy with the IEE TWG which will be

leveraged to insure efficient product prioritization and development.

Charged particle radiation can be categorized in several ways, including ionizing versus non-ionizing, highly directed beams versus isotropic populations, those dominated by collective behavior versus single particle effects, *etc.* A multitude of charged particle effects can impact mission effectiveness. Communication and navigation systems are severely impacted by erratic ionospheric storms. Spacecraft surface charging can lead to electrostatic discharge currents between differentially charged spacecraft, between space vehicles, or between astronauts and spacecraft during Extra-Vehicular Activities (EVAs). Penetrating charged particles can accumulate on internal cables, circuit boards, and isolated conductors within a space vehicle, resulting in electrostatic discharge currents internal to the spacecraft Faraday cage with effects varying from noise in electronic circuits, to phantom commands, and even catastrophic damage to sensitive circuits. Charged macroscopic dust particles and ionized outgassed materials can be attracted to a charged space vehicle, resulting in contamination of sensitive surfaces. These are only a few examples of the many things that can go wrong during a space mission.

Our long term vision is to develop specific products to cover all phases of the mission development cycle. First would be the proper space environment characterization by drawing on the latest research and data resources. This would essentially form the specification of the natural space environment with all of its variability, both statistical over the long term and impulsive over the short term. Secondly, these data coupled with materials/component/subsystem property measurements would support spacecraft designers, as well as tool/model development. The third step addresses model validation with flight data or system performance, which is essential to insuring an optimized solution for space system applications. The fourth and final step is tool implementation for subsequent predictions of events that may affect astronaut and system safety or performance. The long term goals would be to provide timely updates to charged particle environment models (both climate and weather) and their interactions with spacecraft. Additionally, we would potentially serve as partners with customers to assist them with their mission-specific modeling needs.

2.2. Space Environmental Effects (SEE) TWG

The SEE TWG is responsible for addressing the effects of the space environment on materials and systems. This includes ground test, analysis, and flight experiments. This working group will coordinate with the other two groups to address the materials systems analysis and test priorities of their areas. Like the other two working groups, the SEE TWG will use co-chairs and working group members chosen based on their expertise in various aspects of the discipline area.

Many space environment test capabilities exist across the agency and most are complementary in function. These test facilities are utilized by NASA, its contractors, government agencies, industry, academia and international partners. Many unique capabilities offer opportunities to evaluate materials and sub- system components performance in simulated flight environments including weather encounter impact during ascent, micrometeoroid /orbital debris impact, atomic oxygen for low earth orbit, ultraviolet radiation, charged particle radiation, plasma/charging, thermal extremes, and vacuum exposure. Test data and information are maintained at the test location and test reports are usually provided to the specific customer. These test reports are generally not readily available to the space environments and effects user community as a whole. This limitation results in duplication of effort and in some cases, testing under conditions that may vary from the actual environment the component will experience due to test system limitations. This approach is not the best use of limited resources and in the latter case, results in a Program possibly accepting additional risk. As new materials and technologies are developed, adequate ground testing to evaluate applications into flight demonstrations or spacecraft is essential to maximize potential for success. A coordinated approach will support space material advancement and space system improvements that enable game changing technology implementation during the design, development, testing and orbital operations.

Another key component is continued use of flight experiments for environment characterization, material/component evaluation, and operational verification. Flight experiments are essential to insure environmental models are up to date utilizing the latest data. Flight data also helps insure ground based testing is as representative as possible to real space exposure conditions and helps validate ground test protocol and provide model validation.

2.3 Interplanetary and Extraterrestrial Environments (IEE) TWG

The IEE TWG structure will be similar to that of the other 2 working groups. Co-chairs and working group members will be chosen based on expertise in various aspects of the subject area.

They will meet to define products and their priorities based on needs of the various stakeholders in the spacecraft design and operations communities. There is considerable synergy with the Charged Particle TWG which will be exploited in product prioritization and development.

The IEE TWG is responsible for the space environments encountered in interplanetary space, in the proximity of various solar system destinations, the atmospheres of those destinations, and their surfaces. This includes such diverse locations as Earth-Moon L2, Earth geosynchronous orbit, lunar orbit, Near Earth Asteroid (NEA) surfaces, and Mars' atmosphere. The technical issues include NEA geology, dust transport in the presence of plasma, planetary atmospheres, and plasma depletion in the lunar wake, etc. The products will be used during the design, development, verification, and

operations phases of the programs. The tools will also be useful for anomaly resolution and forensic analysis.

Although some extraterrestrial environments have been characterized by previous missions, the engineering demands of human exploration such as high reliability and extreme weight limitations require a thorough knowledge of the environment. Unmanned mission science return can be enhanced when more precise design environments allow reduction in design margin and more mass available for instruments. For instance, performance of hermetic seals in the presence of dust released from the surface of an NEA during its exploration requires detailed knowledge of the characteristics of that dust and its transport depends on interaction with the solar wind and solar ultraviolet. Aerobraking of an unmanned spacecraft using Neptune's atmosphere requires a precise model of the atmosphere so propellant margin can be reduced. Improved models and tools to define these sorts of environments to allow more efficient design and more reliable operation of manned and unmanned spacecraft are needed. This TWG will identify those products and see that they are properly developed to suit the needs of users.

The TWG will consist of environments specialists, space scientists, and planetary scientists who have supported programs to or have done research on these destinations. Their knowledge of the design and operations issues as well as their familiarity with existing models and datasets will ensure proper prioritization and development of the products needed for future missions.

3. RECENT UPDATES

The Mars Global Reference Atmospheric Model (Mars-GRAM) is now publically available. Mars-GRAM is an engineering-level atmospheric model, widely used for diverse mission applications. Applications include systems design, performance analysis, and operations planning for aerobraking, entry descent and landing, and aerocapture. From 0-80 km altitude, Mars-GRAM is based on NASA Ames Mars General Circulation Model (MGCM), while above 80 km it is based on Mars Thermospheric General Circulation Model (MTGCM). Mars-GRAM and MGCM use surface topography from Mars Global Surveyor Mars Orbiting Laser Altimeter (MOLA), with altitudes referenced to the MOLA constant potential surface (areoid).

The Venus Global Reference Atmospheric Model (Venus GRAM) is now publically available. Venus-GRAM is based on the Committee on Space Research (COSPAR) Venus International Reference Atmosphere (VIRA), and is suitable for a variety of engineering applications at all altitudes, locations, and times within the atmosphere of Venus.

The NASA/Air Force Spacecraft Charging Analysis Program (NASCAP-2K) version 4.1 is now available from the Space Environments and Effects Program web site².

NASCAP-2K version 4.1 has a large number of enhancements and a new database. The new database allows for more materials, more particle species, and larger grids for calculations of potentials in space. Additionally, the installation of version 4.1 includes full documentation of the scientific and numeric models incorporated in the code. Version 4.1 is currently available. A new spacecraft definition tool, Object Toolkit (OTk), provides easy, interactive spacecraft geometry definition. A new user-friendly graphical user interface, (GUI) simplifies many of the old, cumbersome operations. NASCAP-2K can create realistic geometric models, simulate charging, and calculate and display surface potential/currents, space potentials, and particle trajectories.

Efforts are underway to convert the Satellite Contamination and Materials Outgassing Knowledgebase (SCMOK) from a standalone PC installation to a web based solution accessible through a link on the Space Environments and Effects (SEE) website and housed within the Materials and Processing Technical Information System (MAPTIS). This knowledge database consists of several parts: E1559, Flight Data, Midcourse Space Experiment (MSX), Contaminate Optical Properties, and Global Search.

4. SUMMARY

The scope of this proposed SENSE organization will be to support design, development, and operation of spacecraft systems enabling them to accommodate or mitigate effects due to interaction with the space environment. The purpose of the SENSE organization includes developing products that define the space environment, increasing our understanding of spacecraft- environment interactions from the materials to the systems-level, establishing space environments related engineering guidelines, and establishing an organization that enables coordination for the National space environments, space weather, and spacecraft effects communities.

The establishment of an Agency level Space Environments and Spacecraft Effects (SENSE) organization would provide: a venue enabling transition of research products to applications and product development management, product dissemination to the aerospace community, gap analysis of the current state of products/knowledge, and a coordination point for the National space environments, space weather, and spacecraft effects communities.

Presently, no agency-level organization exists to enable coordination with the many varied space environments and spacecraft effects related entities. These entities include chartered and well-structured program offices focused on a specific environment domain, and test facilities specializing in critical aspects of material test and analysis.

NASA Programs and projects are currently responsible to develop their own space environment products, at times without significant guidance from (SME's). This is an

inefficient use of NASA resources since it results in duplication of effort in product development and ground testing of materials and systems.

Smaller budget programs have accepted the risk of performance degradation due to space environment interaction with their spacecraft rather than spend the resources to ensure their systems will accommodate the influence of the space environment. This is especially true of the emerging commercial satellite industry that is driven by affordability.

The near-term approach to establish the SENSE organization is to secure appropriate resources, identify and initiate tasks that will have significant and rapid impact on spacecraft programs, launch the SENSE organization, develop a communication strategy, and generate a 5-year plan.

The longer-term approach will build on the initial accomplishments and include hosting yearly meetings to evaluate the state-of the art in space environments and spacecraft effects, perform a gap analysis with inputs from the Nations' experts in the field and use this information to assist in determining funding strategies for the following year. International partnerships are desired and will be pursued to the fullest extent possible.

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References

1. http://www.nasa.gov/pdf/516579main_NASA2011StrategicPlan.pdf, February 14, 2011
2. <http://see.msfc.nasa.gov/>.

An Overview of the Space Environments And Spacecraft Effects Organization Concept

Extraterrestrial
Environments

Meteoroids

Magnetic
Fields

Ionization
Radiation

Vacuum

Thermal
Cycle

Material
Contamination

Interplanetary
Environments

Plasma/Space-
craft Charging

Earth
Albedo

Atmospheric
Drag

Atomic
Oxygen

Solar
Ultraviolet

Orbital
Debris

This Space Environments and Spacecraft Effects concept has been shared with other field centers and agencies with positive response



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JPL	Hank Garrett, Karla Clark, Brian Muirhead
GRC	Sharon Miller, Mike Piszczor, George Schmidt, Jim Gaier
JSC	Darilyn Peddie
NOAA	Terry Onsager, Bill Lapenta, Doug Biesecker
US Army SMDC	Larry Burger



Current State:

- NASA policy, since 2005, is for each program and project to fund their own efforts to determine and implement their space environment and spacecraft effects activities.
- There are numerous, well functioning, entities staffed with subject matter experts, scoped to advance the state-of-the-art in distinct disciplines, disseminate information, and develop products relative to space environment, space weather forecasting, and space systems effects.
 - US Gov't (LWS, MEO, SWPC,...)
 - International (ESA, JAXA, DLR,RKA,CNES, ONERA)
 - Academic (USU, Texas A&M, Vanderbilt)
 - Industry (Boeing, Aerospace, Lockheed-Martin)
- There is minimal progress on long-lead time space environment and spacecraft effects products that focus on the needs of the spacecraft developer
- Numerous existing tools need updating (last update prior to disbanding of SEE program in 2005)
- Dissemination of information occurs through a variety of means:
 - Technical publications,
 - Test report to Program,
 - Analysis delivery to customer,

Space Environments and Spacecraft Effects



Problems:

1. There is no single resource for either government or commercial spacecraft designers/developers to aid them in understanding the space environment and the impact on spacecraft design. The result is dependence on limited websites, personal contacts, a costly overdesign approach, or the acceptance of unknown risks.
2. There is no single coordinating function in space environments , space weather, and spacecraft effects. This has resulted in duplication of effort, gaps in coverage and lingering disagreements over key technical issues.

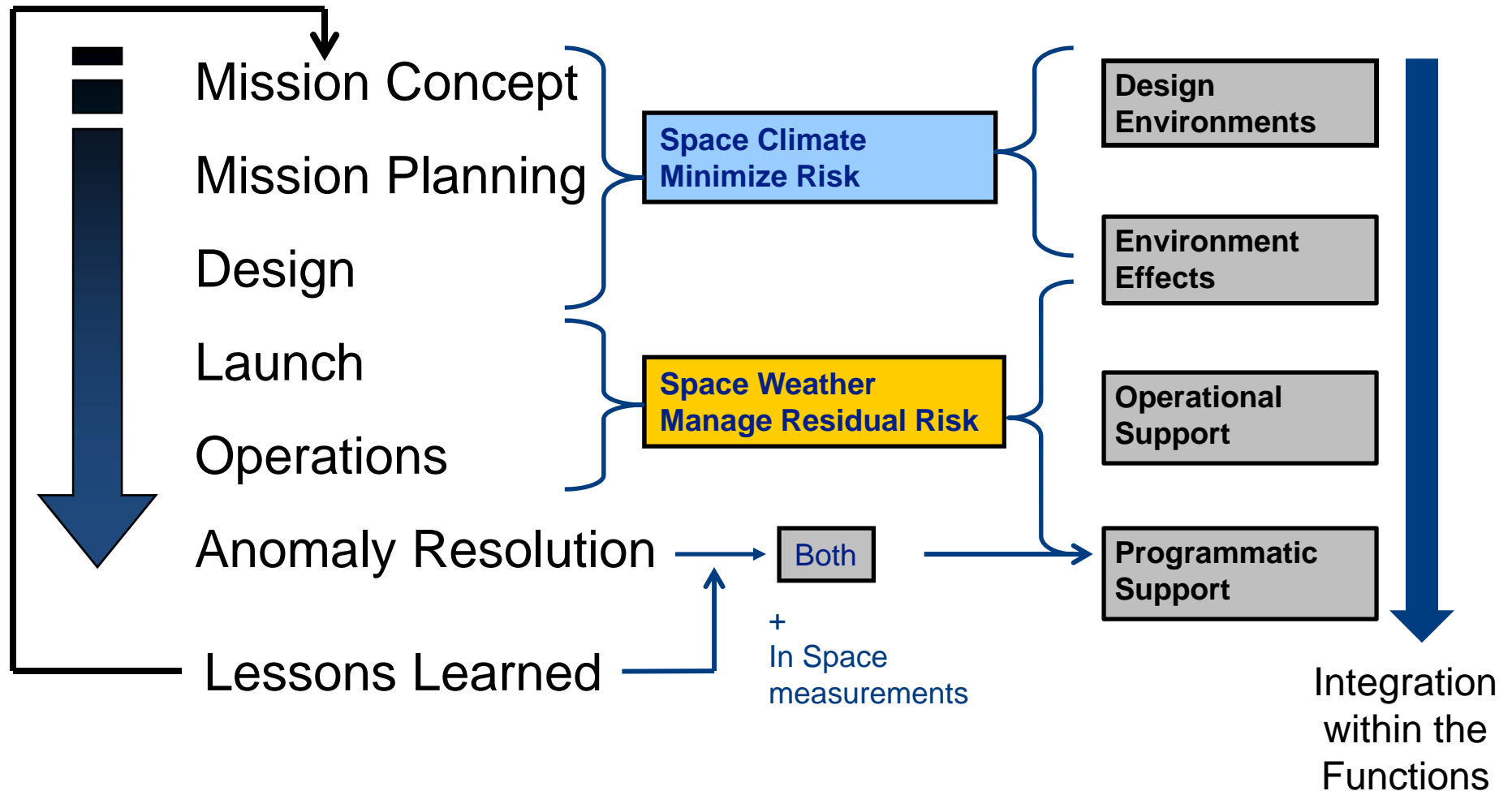
Changing Climate:

- Continued emergence of commercial sector developing spacecraft, NASA's goal of exploration beyond LEO, shrinking budgets, and focus on optimization of limited Agency resources have strained abilities to mitigate and manage risk associated with spacecraft interaction with the integrated space environment.

Solution:

- Establish an organizational structure to focus on;
 - Developing and funding space environment and spacecraft effects products and direct customer assistance,
 - using a successfully demonstrated research to applications approach (SEE, SEVIR, SPoRT),
 - that support design, development, and operation of spacecraft systems,
 - that enable spacecraft to accommodate or mitigate the effects due to interaction with the Space Environment,
 - Performing gap analysis,
 - Facilitate coordination amongst well established discipline areas within NASA, other federal agencies, commercial space industry, academia, and subject matter experts (SME).

Space Environment Model Use in Mission Life Cycle



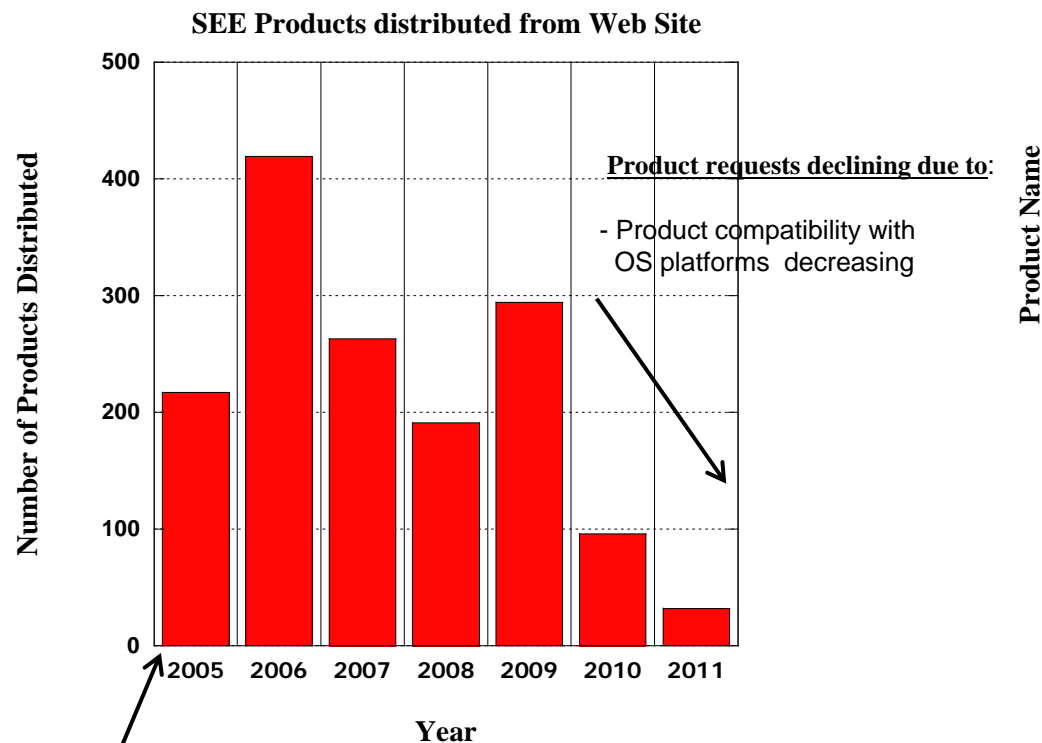
Space Environments information is critical during all phases of spacecraft life cycle



Grand Challenges

- Achieve a comprehensive understanding of the Space Environment and its influence on spacecraft performance
- Transition knowledge and understanding of space environments to applications that are needed by users and operational customers
- Provide commercial and government spacecraft developers and operators easy access to the diverse and distributed information they need to reduce the cost of and risk to their system
- Facilitate National coordination in the discipline of space environments and spacecraft effects
- Enable stable and sustainable funding for near-term and long-term product development

New SENSE Organization will Build on the SEE Program and Expand Scope

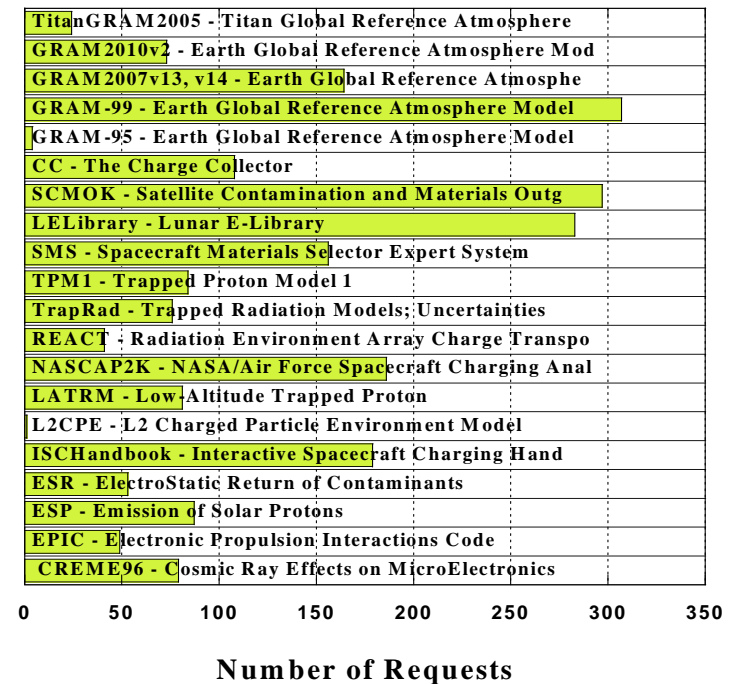


SEE Program Office
terminated 2005
(approx. \$2M/yr)

SEE Program Technical Working Groups

- [Electromagnetic Effects & Spacecraft Charging](#)
- [Ionizing Radiation Environment](#)
- [Materials and Processes](#)
- [Meteoroids and Orbital Debris](#)
- [Neutral External Contamination](#)
- [Ionosphere & Thermosphere](#)

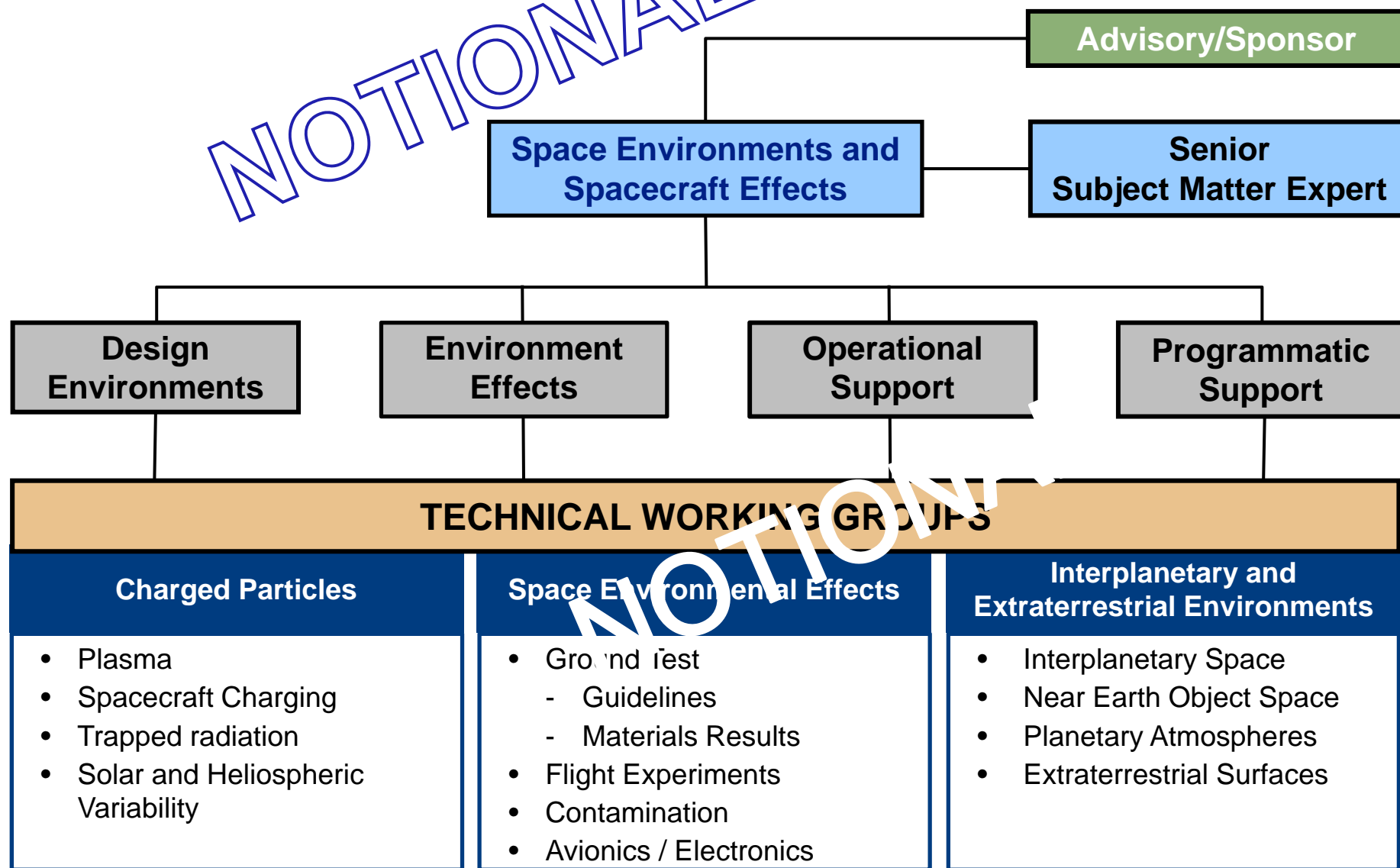
SEE Product Requests



SEE Product User Community

NASA Programs,
NASA Science, and Engineering Organizations,
Federal Agencies,
Academia,
Commercial,
International Space Agencies.

Organizational Functional Flow



Technical

- Focus on those items that are *most* in demand by the user community and can be accomplished in FY12
 - Improved Emission of Solar Protons (ESP) code.
 - Earth-Sun and Earth-Moon Lagrange points charged particle radiation environment characterization.
 - Update the existing Satellite Contamination and Materials Outgassing Knowledgebase
 - Assemble, and make accessible, data sets of materials flight experiments data

Organizational

- Focus on establishment of the Space Environments and Spacecraft Effects organization
 - Develop communication strategy
 - Establish management office and leadership at other field Centers
 - Define and implement roles and responsibilities
 - Set up business office infrastructure
 - Initiate agreements, MOU's.
 - Set up web site for communication and product distribution
 - Define product distribution process
 - Develop educational package on the SENSE organization and initiate conducting training courses.
 - 2 weeks of organizational planning
 - Host 'Kick-Off' Workshop for SENSE participants, commercial user, programs, academia, International

Summary



- The scope of this proposed SENSE organization will be to fund the development of products using a research to applications approach to support more affordable design, development, and operation of spacecraft systems that will accommodate or mitigate effects due to interaction with the space environment.
- The purpose of the SENSE organization includes;
 - developing products that define the space environment,
 - increasing our understanding of spacecraft- environment interactions from the materials to the systems-level,
 - establishing space environments related engineering guidelines,
 - establishing an organization that enables coordination for the national space environments, space weather, and spacecraft effects communities
- The establishment of an Agency level Space Environment and Spacecraft Effects (SENSE) organization would provide;
 - a venue enabling transition of research products to applications and product development management,
 - product dissemination to the aerospace community,
 - gap analysis of current state of the products/knowledge,
 - a coordination point for the national space environments, space weather, and spacecraft effects communities